Algorithm of arranging optimal network for monitoring of gas and aerosol admixtures of anthropogenic and natural origin

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We consider an algorithm of arranging an optimal atmospheric monitoring network. Such an algorithm is needed in determining minimum number of reference points that would provide for obtaining efficient solution of inverse problems of the atmospheric pollutants dispersal. The algorithm uses successive solution of direct problems on the admixture spread from known sources with the option of selecting variants using some preset selection criteria. An example of determination of the optimal atmospheric network is presented.

The problems of atmospheric monitoring and simulation of pollutant dispersal are of both basic and applied significance. The growing anthropogenic load on the environment and anthropogenic and natural disasters involving emissions of harmful substances into the atmosphere stimulate the human environmental protection activity. From this viewpoint, the routine monitoring the atmospheric pollutants concentration is an essential part of this activity. On the other hand, the resources available not always meet the requirements of an extensive development of the atmospheric monitoring networks.

In this situation, the problem on optimizing the monitoring networks becomes practically important. For example, one of the particular problems is organization of optimal network of control points aimed at detection of an industrial source, responsible for hidden emission of pollutants into the atmosphere. Another one urgent problem is the arrangement of the optimal network of control points to look for other hidden sources, for example, of natural origin or those being a result of terrorist attack.

In this paper, we consider an algorithm for arrangement of an optimal atmospheric monitoring network that would allow one to determine the minimum number of control points for obtaining an efficient solution of the inverse problems of pollutant dispersal in the atmosphere, namely, detection of an industrial source, responsible for a hidden emission of pollutants into the atmosphere.

In Refs. 1–4, we considered the efficient method for solution of the inverse problems based on the use of equation conjugate to the semi-empirical turbulent diffusion equation. In particular, it was shown that for its practical application it is necessary to know the concentration of the atmospheric pollutant at least at three control points (measurement sites). This condition is the basic one, but not the sole requirement to the measured values of the concentration. Other additional conditions needed for construction of the optimal monitoring network will be considered below.

The algorithm for solving the problem uses the successive solution of direct problems aimed at the determination of the concentration fields of a pollutant emitted by known sources with the option of selecting variants using some preset selection criteria. Assume that the arrangement of all industrial plants and the effective heights of pollutant sources are known. Let N be the number of such sources and M be the number of weather stations, divided into classes and intended for solution of direct problems of spread of gas and aerosol pollutants in the atmospheric boundary layer. Then $K = NM$ is the number of possible variants, for which the direct problem is to be solved. The entire horizontal region, in which sampling points will be arranged, is covered by a network with rather small rectangular cells. A control point (monitoring site) equipped with the instrumentation measuring the pollutant concentration is placed at every node of this network.

Describe the main stages of the algorithm for construction of the sought optimal network for atmospheric monitoring:

1. At the first stage, the direct problem is solved for the first of K possible variants. Determine the domain of influence for this variant as the zone, in which the observed pollutant concentration exceeds some preset value C_0. The values of C_0 depend, on the one hand, on the sensitivity of the instrumentation used, and, on the other hand, they should be significantly higher than the background value to unambiguously demonstrate that the substance detected has been emitted from an industrial plant. Possible combinations of three control points from the domain of influence are considered for this variant. As was mentioned above, any of the three points in

this domain is sufficient to solve the inverse problem and find the source in this variant. The combinations of three points are marked and stored.

2. At the second stage, the direct problem is solved for the second of K possible variants. Different three-point combinations are considered, marked, and stored. Since the domains of influence of the first and second variant may overlap, some three-point combinations can fall within the domains of influence of both the first and the second variants. These combinations are marked by a symbol, indicating that they take part in two variants.

3. Then consider in a similar way all other variants, for every new three-point combination check, in how many variants it takes part, and store this number along with the list of the variants.

4. Upon consideration of all K variants, we have all three-point combinations present in these variants. Thus, for every three-point combination we know the number of variants (this is called the efficiency of this three-point combination) and in what variants it is present.

5. Determine the three-point combination with the highest efficiency. The result may be not only one, but several three-point combinations with the highest efficiency. If the variants including these combinations do not overlap, then the combinations are stored and the algorithm goes to the sixth stage. If the variants do overlap, that is, at least one variant includes two different three-point combinations, then the combination, whose points are present in the maximum number of variants, is selected.

The three-point combinations selected in this way are stored. All the variants, in which they take part, are marked and removed from the initial K variants. These points form a part of the sought network of control points.

6. For the rest variants and rest three-point combinations, repeat Stage 5 until no one combination with the efficiency higher than unity is rest. For the combinations with the unit efficiency, that means that they are present in only one variant, the one is selected, whose points are present in the maximum number of variants.

As a result, this algorithm yields the optimal network of monitoring stations: the minimum number of sampling points, ensuring the solution of the inverse problems for any of the K variants.

The theoretical analysis and test calculations have shown that the solution of the formulated problem, namely, the optimal monitoring network is not unique. Therefore, at the stage of selection of the three-point combinations it is necessary to invoke the following additional conditions:

The distance between the points in the combination should not be smaller than some value $R_{\min}$. Otherwise, the proposed mathematical model considers such points as one point.

To avoid the effect of the boundaries of the considered region, the points should be separated from the boundaries by no less than three periods of the network.

Also it should be taken into account that at some locations the monitoring sites cannot be placed for the reasons that have nothing to do with the model or the algorithm.

The estimates show that the number of possible three-point combinations will be not very large and can be processed on a modern personal computer for a reasonable time.

To check this algorithm, we have constructed examples of optimal networks for different weather conditions and different limiting values of the concentration. Figure 1 shows one of such examples. The network was constructed for a horizontally homogeneous 30×30 km area with five stationary point sources located symmetrically at the height of 50 m and characterized by the same emission of 10^6 g.

Fig. 1. Example of the network constructed for atmospheric monitoring: point sources (triangles), control points (circles).

Two values of the wind speed: 3 and 5 m/s at the vane height and eight wind directions were considered. The weather conditions typical of Western Siberia in June at 15:00 L.T. were taken into consideration. Thus, the total number of the variants considered was $K = 5 \cdot 16 = 80$. The limiting value of the concentration was set as $C_0 = 0.025$ g/cm^3. The direct problem of pollutant spread was solved by the methods described in Ref. 5. The total number of three-point combinations falling within the domain of influence of these variants amounted to 116 728.

As a result, the network of 68 control points shown by open and closed circles in Fig. 1 was obtained. This is the minimum set of points permitting solution of the inverse problem and detection of the unknown source under specified weather conditions and preset sources of pollution. It is obvious that, in view of the axial symmetry of the example under consideration, the obtained monitoring network must be symmetric. This is one of the criteria of the correct operation of the algorithm for the considered example. Rejection of any of the control points in the network results in the situation that at least in one of the K variants it becomes impossible to solve the inverse problem.

The number of control points obtained in this example (68) is not small even for a big industrial city. This number can be much smaller, if we exclude the variants, in which the source is located in suburbs and the wind blows from the city. In this case, the domain of influence of the source lies beyond the city and it is possible to omit the corresponding variants and reject the corresponding control points (closed circles in Fig. 1).

It is clear from Fig. 1 that if we omit such variants and reject 36 points located between the source and the nearest boundary of the considered area, then their number decreases down to 32. It is obvious that if we decrease the limiting concentration, the number of control points decrease too. In this case, the domains of influence and overlaps for every variant are much larger and, consequently, the three-point combinations falling within the overlapped regions serve much more variants.

The test calculations have shown that, in constructing the optimal network of monitoring stations for particular cities, real weather conditions, and much greater number of potential sources, the total number of stations remains roughly the same, though the total number of variants K is many times greater. This is explained by the fact that the domains of influence of the most variants overlap and the efficiency of the three-point combinations increases, that is, the same combinations are used in much more variants.

In conclusion, it should be noted that this idea, though in a somewhat transformed form, can also be used for detection of sources, whose location is unknown.

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